

**POWER TECHNOLOGY FOR FUTURE
NASA SCIENCE MISSIONS**

Perry Bankston
Jet Propulsion Laboratory
April 29, 1997



Space Science Themes

Sun-Earth connection

Mission To Planet Earth

Solar System Exploration

Mission From Planet Earth

Origins

Structure and Evolution of the Universe



Formation of the Universe

1980



Formation of Solar Systems

1990



Origin and Distribution of Life

2000



The Solar System and Planet Earth

PRESENT



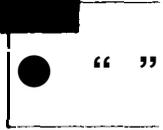
Future Habitability and Human Destiny

2020

Time



From Clouds to Stars to Planets



Spectroscopy and Imaging from the Ground and in Space



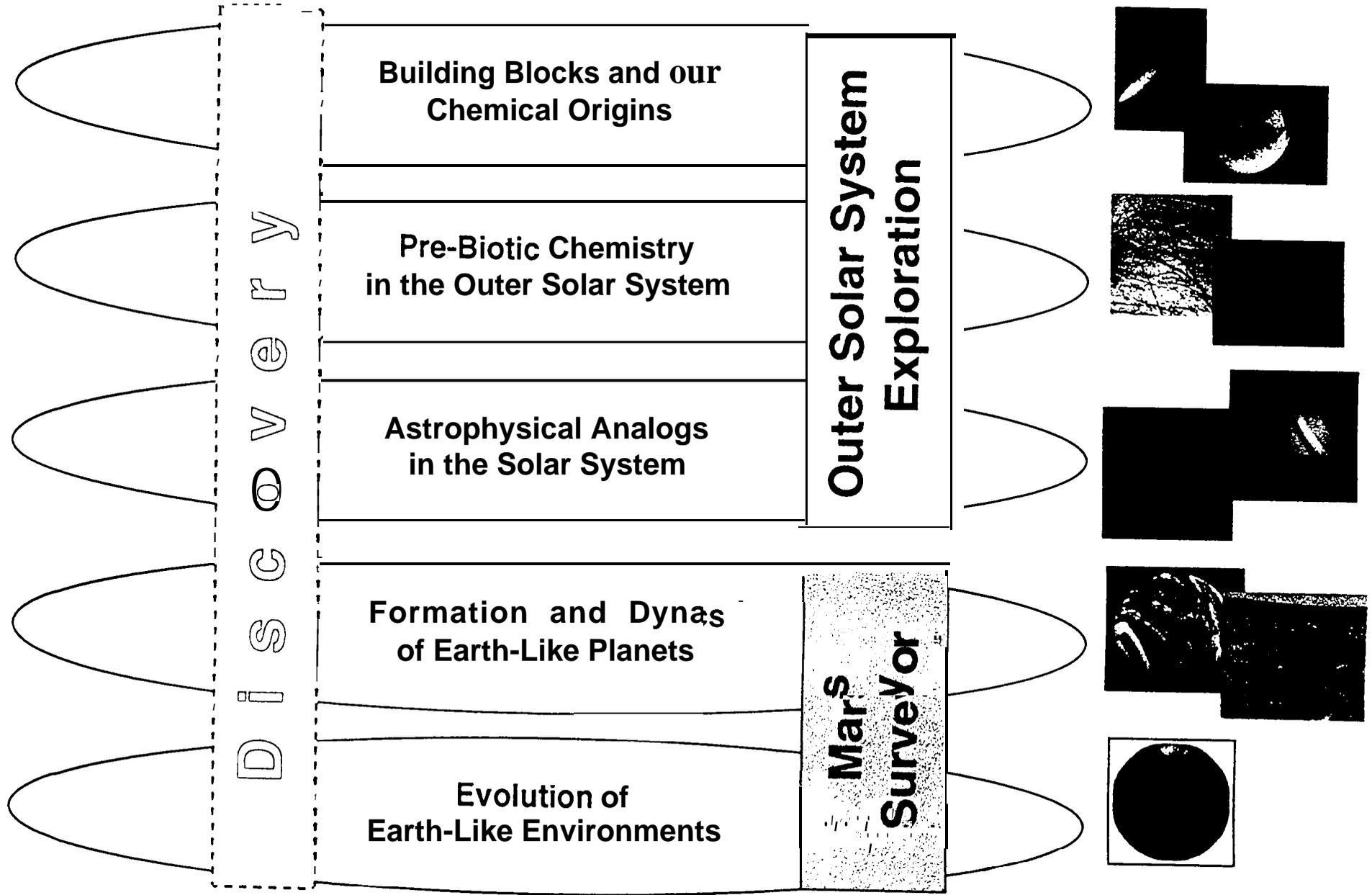
Interferometry for Planet Detection and Imaging



Mission to the Solar System: Remote, In Situ, Sample Return



Solar System Exploration Campaigns and Cross-Cutting Programs



Chemical Origins and Pre-Biotic Chemistry: An Integrated Mission and Technology Program

2000

2002

2004

2006

2008

Advanced Deep Space System Development (CISM, RPS, Outer Planet Technology)

ADVANCED
FLIGHT SYSTEM

X2000

X2003

X2006

OUTER PLANETS/
SOLAR PROBE
(Actual sequence TBD)

Europa



Pluto



Solar Probe

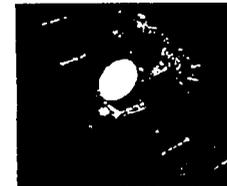


Comet Sample Return



PRIMITIVE BODY
EXPLORATION

MUSES-CN



Champollion



NEW
MILLENNIUM
MISSIONS

DS
1-2

DS
4

EXPLORATION
TECHNOLOGY

MUSES-CN
NANO-ROVER
SYSTEM

SAMPLING
SYSTEMS

SENSORS

PRECISION
LANDING

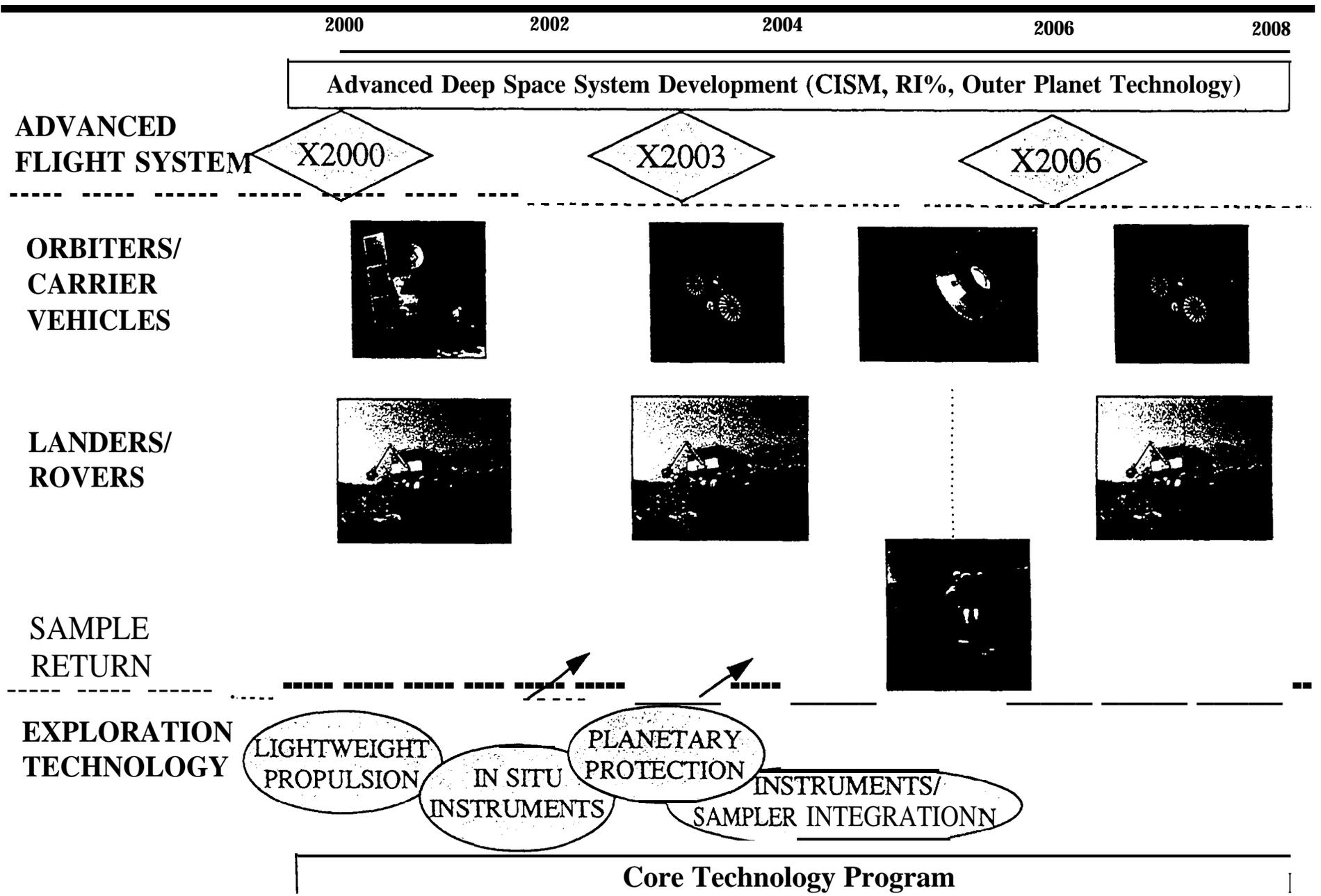
SUBSURFACE
SAMPLING

INTEGRATED
LABS

Core Technology



Mars Exploration: Integrated Mission and Technology Program



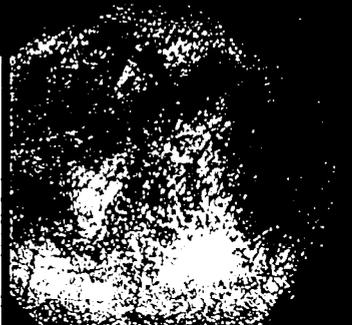
JPL OUTER PLANETS EXPLORATION PROGRAM

... high-yield science at the most difficult destinations

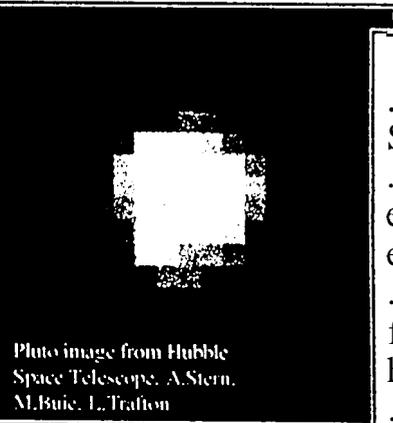


Europa Orbiter

- Confirm & characterize possible subsurface ocean.
- Focus the search for possible biologically-relevant discoveries.
- *Extreme propulsion and radiation demands.*
- *Exacting measurements to build on Galileo results.*



Europa from Galileo
September, 1996



Pluto image from Hubble Space Telescope. A. Stern, M. Buie, J. Trifon

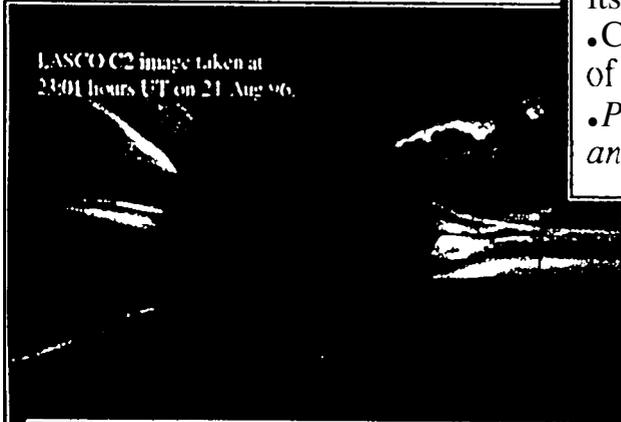
Pluto-Kuiper Express

- Complete our reconnaissance of the Sun's planets.
- Characterize Pluto/Charon, expect ≥ 1 Kuiper Disk Object encounter.
- Survey remnant bodies in region from which Earth's volatiles may have come.
- *Extreme distance and long lifetime.*
- *Pluto headed away from Sun.*

Jupiter Deep Probes

- Explore the nature and dynamics of Jupiter's atmosphere to depths where its fundamental composition is represented.
- Characterize Jupiter as a key representative of planets being detected around other stars.
- *Probing to extreme temperatures and pressures.*

LASCO C2 image taken at 23:01 hours UT on 21 Aug '96.

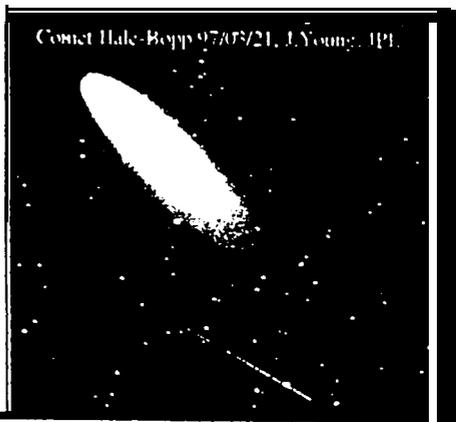


Solar Probe

- Explore the source of the Sun-Earth connection.
- Origin of Solar Wind and Coronal heating.
- *Extreme heat, thermal range, and challenging measurements near Sun.*



Comet Hale-Bopp 97/08/21, J. Young, JPL



Comet Nucleus Sample Return

- Return pristine comet nucleus material to Earth.
- Acquire detailed *in situ* sample context measurements.
- *Sampling system, sensors, autonomy, solar-electric propulsion.*

JPL Comet Nucleus Sample Return

(Science Mission)



Science Objectives

Increase understanding of early Solar System composition, potential source of Earth organics/volatiles.

Acquire sample(s) from ≥ 1 site(s) on a comet, return [()] Earth.

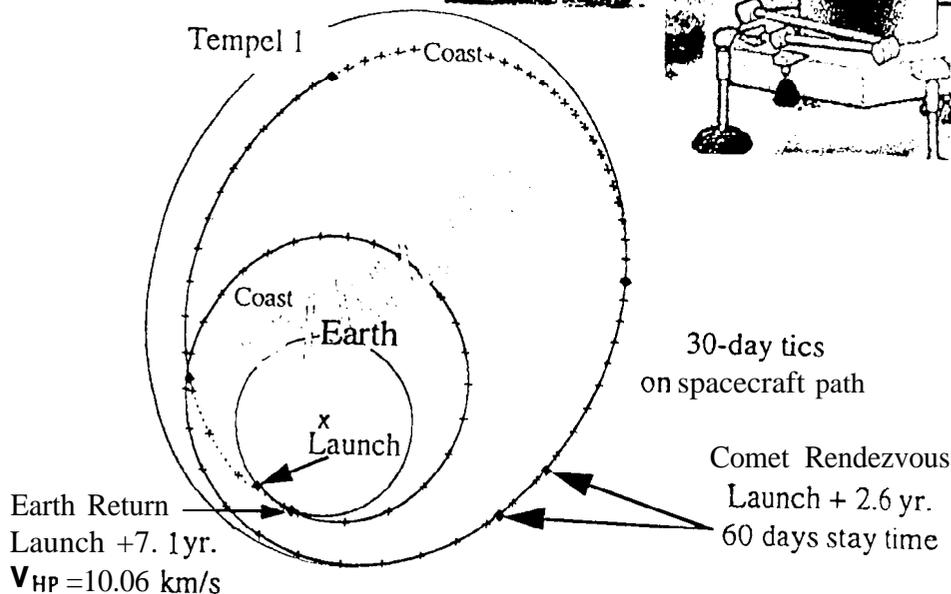
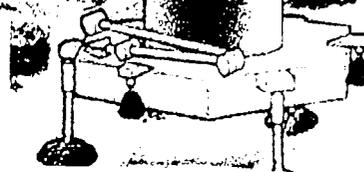
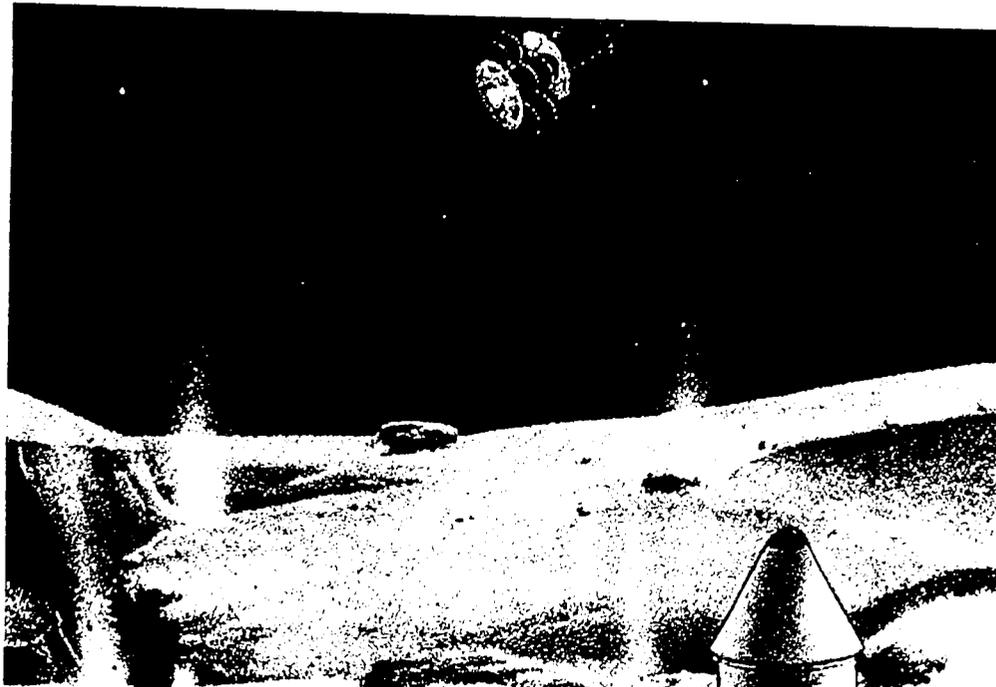
- Total 200g
- Samples sealed and maintained $< 300 K$
- Stratigraphy preserved
- *In situ* analysis of volatiles

Key Technologies

- Relics on Champollion.
- Advanced SEP and solar arrays.
- GN & C for rendezvous, landing, sample retrieval.
- Sample acquisition, handling, preservation.

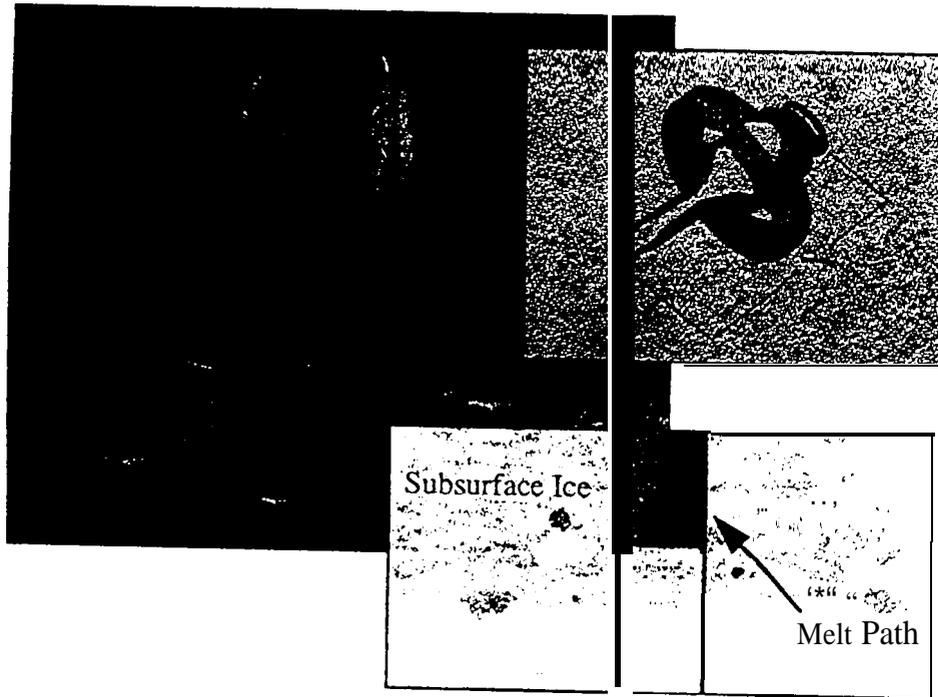
Mission Concept

- Delta II Launch.
- Solar Electric Propulsion out and back.
- 7 years for launch to Earth return.
- Lander similar to Champollion.
- Sample retrieval via tether or rendezvous.



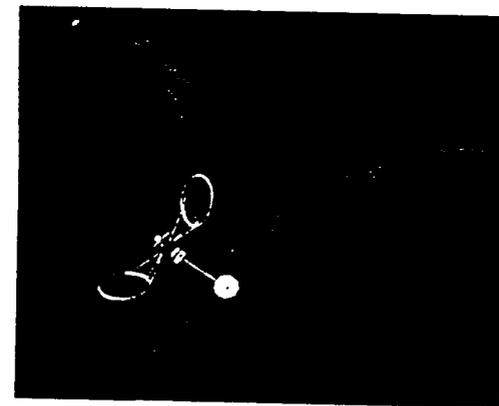
Outer Solar System Exploration Breakthrough Science and Technology:

Europa Ice Lander



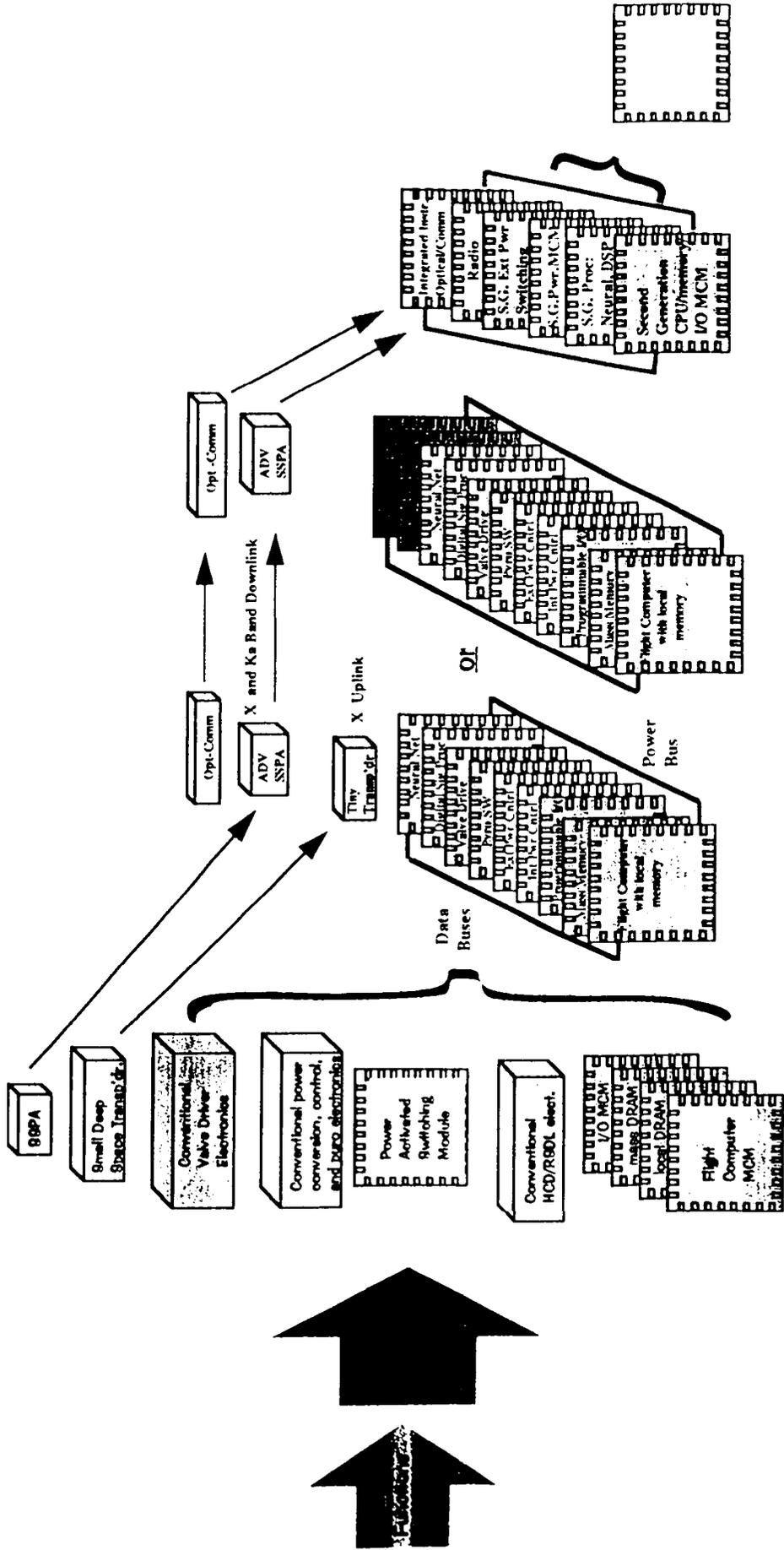
- Soft landings on icy moons
 - Chemical analysis of surface material
 - Seismic and geophysical studies
 - Demonstration of thermal penetration
- 10 kg lander containing prototype miniature lab and thermal package
- Slow melting through ice.. fiber optic link to surface antenna
- Breakthroughs in airless body landing, thermal control, telecom
- Initial deployment from Europa Orbiter

- Europa, Ganymede, Callisto
- Similar applications for Mars polar ice caps
- Earth: Exploration of glacial depths and subsurface Antarctic lakes



Advanced Deep Space System Development

Upgradable Electronics Architecture Advancement with "Plug and Play" MCM 3D Stack



NMP DBI

Some assemblies on a chip

X2000 Delivery

Assemblies on a chip

Future Delivery

Subsystems on a chip

Far Term

"Spacecraft on a chip"

HCD/RSDL = Hardware Command Decoder/Need Solar Downlink
 MCM = Multi-chip Modes
 NMP = New Millennium Program

PWR = Power
 88PA = Solid State
 OPT = Optical
 DBI = Deep Space 1, 1st NMP Technology Demo Flight

Amplifier



Advanced Power Generation

Improved solar array technology will enable solar-electric propulsion and inexpensive missions to the Jupiter system 50<100 W required at Jupiter

- Up to 15 kW at 1 AU for SEP
- Efficiency exceeding 100 W/kg, compared to 40 W/kg today
- Radiation and thermal tolerance

Solar concentrators to focus sunlight on collector/converter

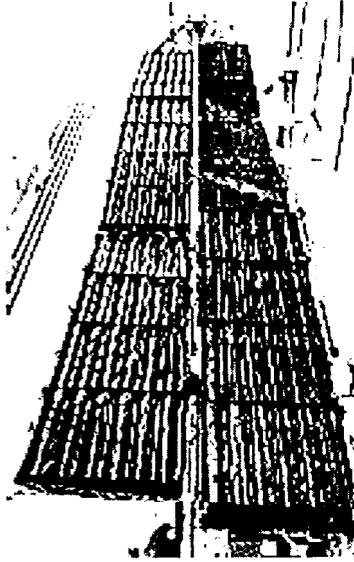
- Inflatables or rigid
- Can enable solar-powered missions to Neptune
- System flight

Advanced radioisotope power generator

- Conversion efficiency exceeding 20%, compared to 4-6% today
- Reduced radioisotope inventory
- Low mass and extremely robust: "Bulletproof"
- Enabling for long-duration missions to very low-sunlight areas and extreme environments



NSSTEP Inflatable Antenna Experiment



Linear Concentrator Array

▶ next

◀ previous

▶ main menu



Leading Technologies: Power for Small Vehicles and Spacecraft

All Components Exist... Integration and Validation Required

NASA ROADMAP
Leading
Technologies

Rev. 9.27.96

Slide 10 of 17

Small photovoltaic blankets for surface rovers and landers

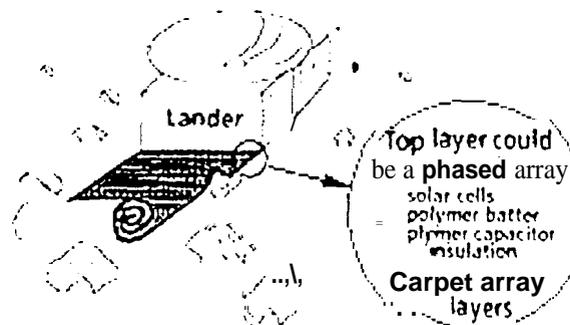
Shock-resistant small arrays for penetrators

Extreme temperature batteries

- Primary/secondary batteries operational at -100 degC (compared to -20 degC today)

Very small long-life power source for planetary surfaces and non-sunlit areas

- Small radioisotope units coupled to converters/batteries
- "Trickle charge" of 1-10 milliwatts
- Power storage and "burst mode" operations



Station with Photovoltaic Blanket



Power Stick

▶ next

◀ previous

▲ main menu

Advanced Radioisotope Power Sources

PRDA Technologies

New heat source

2 W₊ class

62.5 W_t class

New converters

0.10 we class

10 W_e class

100 we class

New therming.

New RHU

Harsh environments

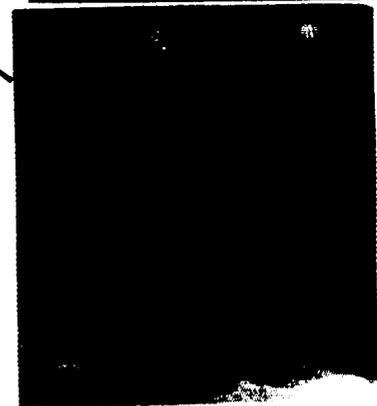
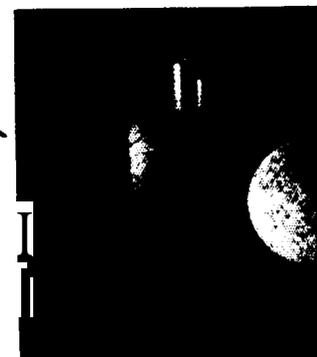
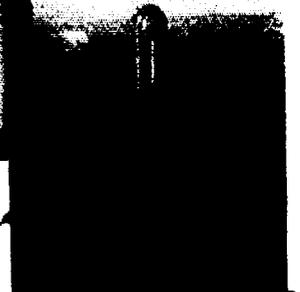
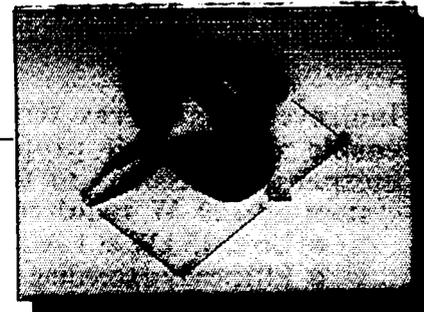
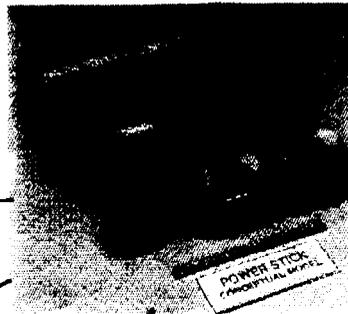
Hermetically sealed

High "g"

High temperature

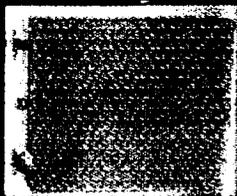
High pressure

High radiation dose

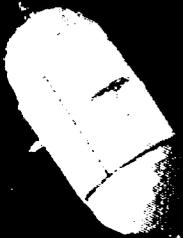


ADVANCED LITHIUM SPACECRAFT BATTERIES

NiCd



Ni-H₂ IPV



2 CELL CPV

Ni-H₂



22 CELL SPV

Ni-H₂

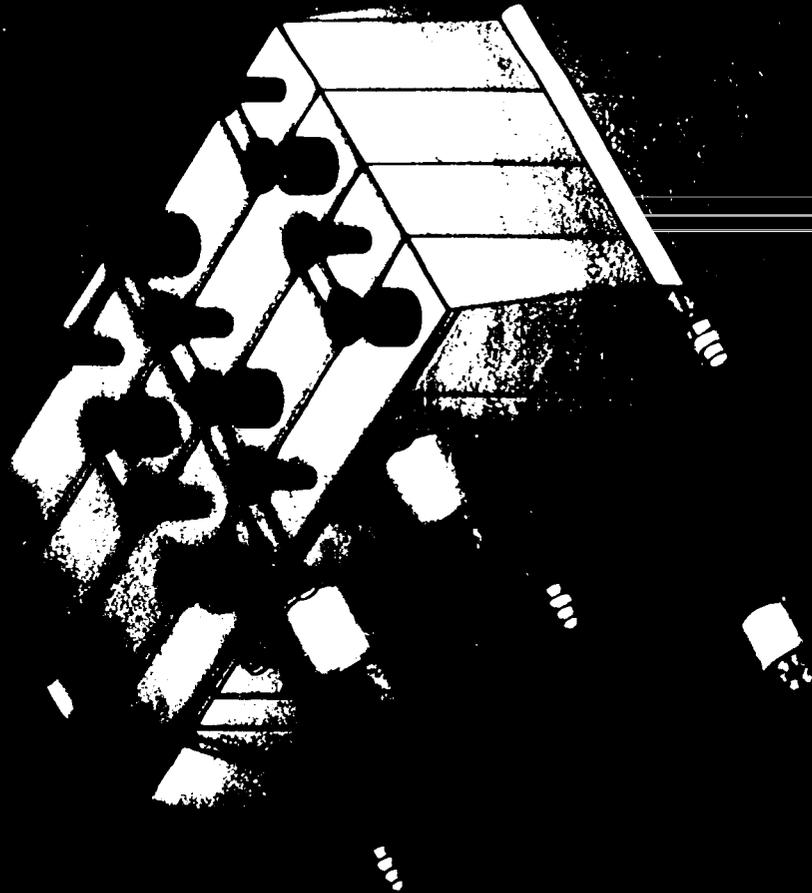


Li-ION



ES/IT

SCHEMATIC OF A 28 V, 20 Ah Li-ION BATTERY



BATTERY INTERFACES

Electrical: (1) Power Connector (J1)
(2) Sensing Connector (J2)
(3) Heater Connector (J3)

Mechanical: 48 Base Mounting Position

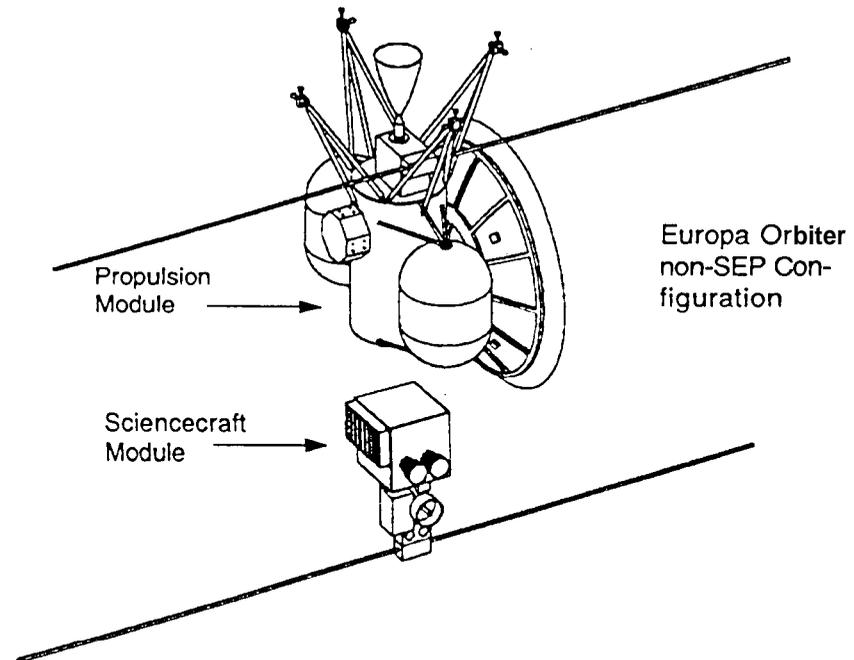
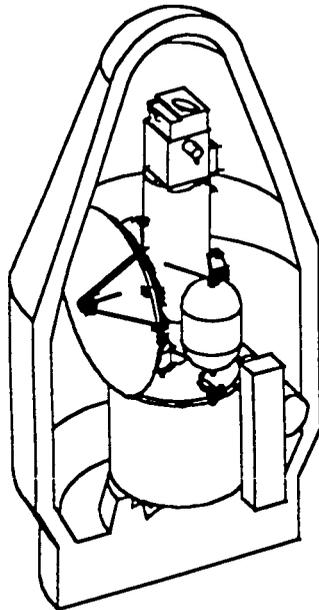
Thermal: Surface mounting Thermal
Baseplate (0-30°C)

WIDTH (U): 12 cm
LENGTH (V): 18 cm
HEIGHT (W): 19 cm
WEIGHT: ~~8.24~~ 5.10 (Kg)

Solar Electric Propulsion (SEP) for Outer Planets

- SEP enables Comet Nucleus Sample Return (CNSR)
- Options being carried for Europa and Pluto; benefits and costs will continue to be weighed.
- Further term technology options will be considered for Solar Probe (e.g. more advanced SEP, solar sail).
- Continuing to explore tradeoffs

Europa Orbiter
with SEP Module
in Delta Fairing

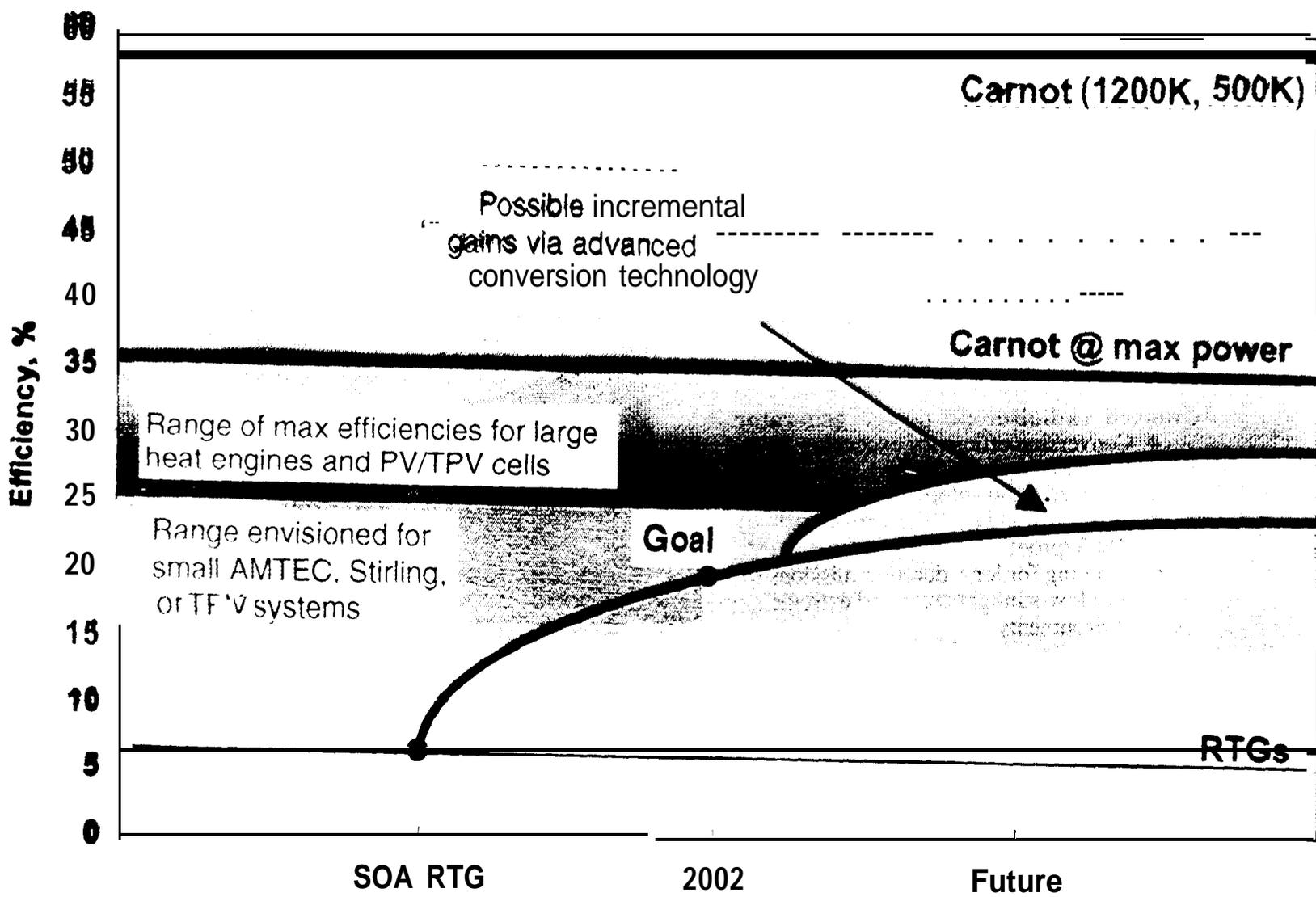


- There are many other missions for which SEP is enabling or enhancing.

TRENDS IN NASA/GSFC SPACECRAFT PROGRAMS

- Future GSFC in-house spacecraft to focus on technology demonstration for earth science and space science missions
- More science missions implemented in “PI mode” (principal investigator is prime contractor and subcontracts for spacecraft bus)
- Most new space science missions on small spacecraft with short development phase and tight budget constraints on power system
- Most science missions operated in low earth orbit with emphasis on power system life cycle performance
- Selected science missions operated in geosynchronous orbit or at the libration point with emphasis on power system efficiency

RPS Efficiency Compared to Carnot

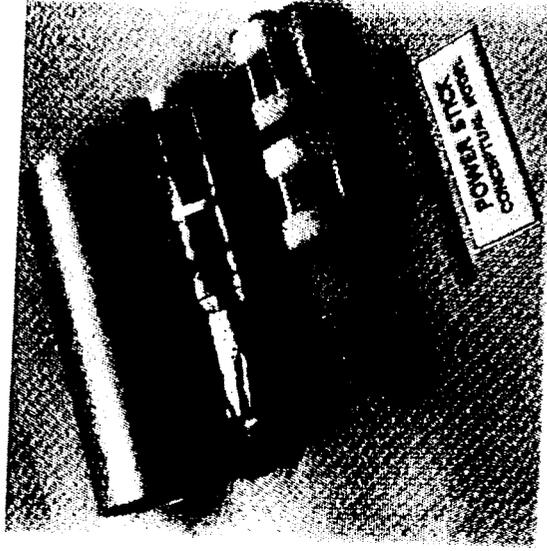


Examples of Integrated Systems



Solar Power and
Radio Frequency
Sys em

Rechargeable Battery and
Small Radioisotope
Power Source



FOCUS OF NASA/GSFC SOLAR CELL ARRAY ACTIVITIES

- Development of composite modular solar array to shorten schedule for small space science spacecraft
- Utilize modular solar array on small space science missions to provide inflight testbed opportunities for new solar cell technology
- Infusion of high efficiency multifunction solar cell technology to reduce area and weight of GSFC spacecraft
- Continued improvement of light weight flexible photovoltaic blankets for high power applications

FOCUS OF NASA/GSFC ENERGY STORAGE ACTIVITIES

- Development of lithium ion technology for space science missions that operate at the libration point
- Development of flywheel technology for energy storage and attitude control to use on advanced geosynchronous weather satellites
- Development of nickel metal hydride technology for space science missions in highly eccentric orbits
- Continued improvement of long cycle life batteries for low earth orbit space science and earth science missions

FOCUS OF NASA/GSFC POWER MANAGEMENT AND DISTRIBUTION ACTIVITIES

- Surface mount technology and high frequency regulation to reduce weight and size of electronics
- Solid state power controllers to eliminate relays and fuses
- Backplane and plug-in modules to eliminate internal harnessing
- Microprocessor control module with most functions in software
- Reconfiguration of modules to meet unique requirements from mission to mission

Acknowledgement

This work was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration